Investigation of Learning Process with TUI and GUI Based on Protocol Analysis

Natsumi Sei[1(✉)], Makoto Oka[2], and Hirohiko Mori[1]

[1] Graduate Division, Tokyo City University,
1-28-2 Tamadutumi, Setagayaku, Tokyo, Japan
G1791801@tcu.ac.jp
[2] Tokyo City University, 1-28-2 Tamadutumi, Setagayaku, Tokyo, Japan

Abstract. In this paper, we evaluated learning process of tangible user interface and graphical user interface. We investigate the effect of the user interface on learning process when user learn by using computer. When TUI and Graphical User Interface (GUI) were used, how an adopted interface may affect learning process was focused. We conducted the experiment to clarify the effect on learning process when a specific interface was used, difference in learning process is to be reviewed by using TUI and GUI. An analysis was conducted for the verification using a protocol analysis. Strategy of problem-solving by using two systems were similar in case of early in the experiment.

Adopting other measures when getting familiar with such problems, however, it has been proved that participants find out a correct answer by accumulating sub-goal achievement in case of GUI and they figure out a correct answer while taking various measures such as searching of clues and accumulation of sub-goal achievement in case of TUI.

Keywords: Tangible User Interface (TUI) · COCOM · Cognitive process · Interface

1 Background

The types of interfaces have become diversified in association with the popularization of computers. Among them, TUI is a type of interfaces through which we can operate computers by directly touching physical objects. One of the advantages of TUI is its easy operation procedures as it enables us to operate computers in an intuitive manner. For this reason, it is thought that we can solely focus on learning activities without paying much attention to how to operate a computer. Researches using TUI in a learning environment have been conducted. However, while some researches have showed that using TUI has an impact on learning environments, how it affects learning processes has not been verified yet substantially.

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2 Purpose

In this paper, how an interface in use influences the learning process will be examined for TUI and GUI. Revealing such influences enables us to provide an interface suitable for learning activities.

3 Related Works

Tablets and notebook PCs are the interfaces frequently used in the learning activities using computers like those making use of ICT. Tablets and notebook PC are featured by their capability to adapt themselves to various classes by changing an application to be used in them. Also, Yokoyama et al. [1] conducted a class using tables PCs for elementary school and junior high school students, the results of which suggested that their ability to think was improved. In addition, Akahori et al. [2] examined the influences on learning by using the three media: papers, PCs and tablets. It was revealed that with papers learners had a high understanding of basic problems and clearly recognized letters, while with tablets they showed a deep understanding of applied problems and a high-level recognition of images. As such, it was demonstrated that influences given on learning vary by a media to be employed for it. Some researches have used TUI in the learning making use of ICT. Kuzuoka et al. [3] utilized a globe as a tangible interface for the learning of astronomy, consequently proposing a learning environment under which we can learn about the relationships between the earth and the sun. It was indicated that learners tended to depend on a system in learning activities so that they were unable to gain an essential understanding and accordingly misguided to a wrong thought. Also, Cuendet [4] conducted a class using TUI. It was found that while the learners became more willing to learn there was no difference produced in terms of their learning effectiveness. Cuendet [5] conducted a class with the use of TapaCarp, meaning that the students could use TUI in the class. It was indicated that using TapaCarp enabled them to gain more positive attitudes toward the class and also to come up with flexible ideas. In the meantime, he said that there was a problem in terms of its versatility for classes. From the above facts, it is understood that using TUI produces a positive effect of their getting motivated to learn. On the other hand, however, it was suggested that TUI was unable to cause a powerful effect in respect of their performances and skills. However, I believe that TUI has not demonstrated a significant result just because there has been no research that verifies how much effects TUI can cause on what kinds of learning activities. Therefore, I think that learning activities using TUI would produce effective outcomes by closely looking at the learning process such as how learners will address their own problems in their learning process and by investigating the influences TUI exerts on them, rather than evaluating outcomes only through their performances.

4 Experiment

4.1 Objective of Experiment

We conducted the experiment to clarify the effect on learning process when a specific interface was used, difference in learning process is to be reviewed by using TUI and GUI.

4.2 Experimental Policy

As a learning task, logical circuit learning was selected in which GUI and TUI showed the same appearance. Subjects were asked to prepare a logic circuit based on a truth table. The three logical symbol used in this experiment was the "AND", the "OR" and the "NOT". In addition, the lead wire objects and the lamp objects, to connect among each gate and to confirm the output of the circuit respectively, were also prepared.

GUI is operated with a mouse using "click" and "drag" while watching on a PC screen. TUI is operated using cube- shaped blocks to create a logic circuit by applying them in 2-dimensional place. Asking subjects to voice what the subjects asked to "think aloud", and, their behavior and verbal protocol data were recorded by VCR.

4.3 Experimental Methodology

Subjects were asked to solve problems using a system to learn logic circuit. Operation manual of the interface was written out on a paper for subjects to be able to read again during experiment and instruction of the logic circuit was also written on a paper likewise.

Experiment was performed for 6 weeks (6 times) by increasing the difficulty every week. Subjects were asked to solve problems taking for around an hour in each experiment. A personality assessment test was conducted in the first week in order to recognize their original strategies. They were asked to solve problems regarding a logic circuit in the second and later experiments. In the second week, such problem was set for them to fill in an output part in a truth table in reference to a logic circuit in order for them to get familiar with a way to read truth tables. From the third and later week, they were asked to solve problems to create a logic circuit from a truth table. The problems of 3th are make logic circuit from truth table. Logical symbol of 3th is 2 pieces, 4th is 3 pieces, 5th and 6th are no specified pieces for increase the difficulty level.

In the 6th, number of available logic symbols was not designated for the problem with a setting of two lamps for output. Because of the increased two output lamp, subjects were required for applied skill different from the case of problems provided in the 5th or before.

5 Analytical Methods

Analyses will be made from three perspectives. The first analysis is to, based on quantitative data, examine how many research participants could solve problems. The second one is a protocol analysis that perform analyses from the narrations and behaviors of the participants. The third analysis a one using the contextual control model being a type of the recognition model. These three analyses are going to be made from their individual perspectives.

5.1 Learning Process

We analyzed the subjects' mode transition based on COCOM by dividing the whole period of the experiment into 3 stages to focus on their learning process as follows:

Initial stage: The third week
The subjects learn the basis of the logic circuits.
Latter stage: The 4th and 5th weeks
The subject becomes accustomed to solve the problems of the logic circuit.
Practical stage: The 6th (using 2 lams)
The subjects are asked to solve some advanced problems.

5.2 Contextual Control Model

In order to analyze what kinds of subject behavior will take, an analysis is made in reference to Contextual Control Model (COCOM) [6] by Hollnagel. There are five modes for COCOM.

Scrambled control mode: A control to select of random or panic.
Opportunistic control mode: A control to select next action just based on the current situation.
Explorative control mode: A control to seek for new ways at a venture without any other option available.
Tactical control mode: A control to select next action according to regulations provided in advance.
Strategic control mode: A control at high level in consideration of overall situation.

An analysis was conducted using an applied model which was adapted for problem solutions in reference to five modes advocated by COCOM.

Scramble control: The state that the user has no idea of what to do to solve the problem.
Explorative control: Their sub-goal is not clear and not to go toward the goal directly but to just try to find something tentatively.
Opportunistic control: Though subjects think looking at only one or a few sub-goals toward the goal, they do not know what kind of action should be done to achieve them.
Tactical control: Subjects think several sub-goals sweeping some part of path to the goal and knows what kind of action is needed to achieve sub-goals though they

have not found the whole Tactical control: Subjects think several sub-goals sweeping some part of path to the goal and knows what kind of action is needed to achieve sub-goals though they have not found the whole path for the goal yet.
Strategic control: The path toward the goal is established more detail than tactical control, and subjects know what action are required to achieve it.

Then, we focus how the five modes of COCOM may transit in problem solving process. It was frequently observed that subjects tried ideas different from thoughts they had in the process of problem solving. With a concept to regard these thoughts as a cluster, how they bring about a transition in the cluster is reviewed.

Without any time limit for the experiments required, such a scrambled control mode to work on problems in panic did not occur. In addition, because the strategic control mode occurred when they were working on an easy problem and did not transit to other mode, the mode was excluded from the current analysis.

6 Results of the Analysis

6.1 Analyses Based on Quantitative Data

The number of the participants who had solved six problems within an hour was organized in Table 1. At the third stage, the participants in both groups were able to solve all problems. At the 4th stage, one participant in TUI group failed to solve problems. One participant in GUI group couldn't answer problems at the 5th stage, while all of the participants belonging to GUI group were unable to solve them at the most difficult 6th stage. At the 3rd stage, as the difficulty level of the problems had been set lower, the participants in both interface groups succeeded in solving them.

Table 1. The number of the participants who had solved six problems. (persons)

	3rd	4th	5th	6th
GUI	3	3	2	0
TUI	3	2	3	2

At the 4th stage, one participant in TUI group failed to answer problems. This is because such participants couldn't handle their increased level of difficulty. One participant in GUI group couldn't solve problems at the 5th stage where the difficulty level of problems had been further raised, while all the participants in GUI group failed to answer them, for they couldn't catch up with their difficulty level. Meanwhile, all the participants in TUI group succeeded in solving problems at the 5th stage at a higher difficulty level and two of them could answer them at the sixth stage being the most difficult. This can be explained by an assumption that TUI enabled them to use a solving method applicable to the problems at a higher difficulty level.

6.2 Protocol Analysis

Looking at the initial stage for GUI group (Table 2), a participant said, "AND and OR cannot be used together, so would it be a reversed flow if connecting them?" This shows that such participant predicts the outcome of a logic circuit to be designed. At the initial stage for TUI group (Table 3), a participant commented, "It lights up only with ONON. Reverse it after turning it around." Such comment suggests that this participant also projected the result of a logic circuit he would design.

At the later stage for GUI group (Table 4), a participant said, "Oh, this is not going to work." which indicates that such participant experienced a result different from the one he had expected and also that his expectation was not accompanied by a proper method. At the later stage for TUI group (Table 5), a participant commented, "I will remember this as it was the other way around.", which tells us that this participant designed a logic circuit for checking its result rather than designing it after making a prediction of its result. At the practical stage for GUI group (Table 6), a participant said, "Light this one and then both. I guess this looks good", which shows that the participant designed a logic circuit while expecting its outcome. Then, soon after, he added, "I wish it will light up", which suggests that his expectation was not a convincing one to him. At the practical stage for TUI group (Table 7), a participant quickly said, "It is AND not OR", which demonstrates that the participant designed a logic circuit for the purpose of using logic symbols occurring to his mind instead of determining them to be used based on a prediction of the result. Taken all together, it was revealed that at the initial stage the participants in both GUI group and TUI group designed a logic circuit while expecting its result. However, at the latter stage, the participants in TUI group demonstrated a different approach to the problems. It was found that those in TUI group would design a logic circuit without predicting its result. Meanwhile, those in GUI group, like the initial stage, designed a logic circuit with predicting its result. At the practical stage as well, there were many comments made by the participants in TUI group suggesting that they were designing a logic circuit without expecting its result, while there were lots of comments made by those in GUI group indicating that they were designing a logic circuit with expecting its result.

Table 2. GUI in initial stage

Time	Action	Protocol
1:45		AND and OR cannot be used together
1:52		So would it be a reversed flow if connecting them?
2:08	Move	
3:13		Not, good?
3:25	Check	
4:04		I want to connect AND

Table 3. TUI in initial stage

Time	Action	Protocol
7:10		It lights up only with ONON
7:11	Move	Reverse it after turning it around
7:22	Check	
7:29	Move	AND …
7:33	Check	

Table 4. GUI in later stage

Time	Action	Protocol
0:01		ONON, OFFOFF, OFFON
0:06	Move	
0:22	Check	
0:27		OFFON
0:32		Light in ONOFF
0:40	Move	
0:51		This is not going to work

Table 5. TUI in later stage

Time	Action	Protocol
9:16	Check	
9:23	Move	It is the other way around
9:27	Check	I will remember this
9:31		

Table 6. GUI in practical stage

Time	Action	Protocol
3:55	Move	
3:57		Light this one and then both
4:02		Like this
4:03	Move	I guess this looks good
4:19	Check	

Table 7. TUI in practical stage

Time	Action	Protocol
27:25		I wonder what about
27:35	Move	It is AND not OR
27:45	Check	Are different
27:50	Move	
27:52	Check	

6.3 Probability of Transition of Mode by COCOM

It was found that research participants tried more than one method in solving one problem. Their strategy is going to be discussed by examining how they made mode transitions in a single trial. Figures 1 and 2 illustrate the probability of mode transitions. The color gets thickened as the probability gets higher; The color goes white as the probability gets lower. Whereas the transition to the tactical control mode was frequently observed with the use of GUI at the initial stage, the transition between the tactical control mode and the opportunistic control mode as well as that to the opportunistic control mode were seen very often at the later stage and the practical stage (Fig. 1). With TUI, many research participants made transitions from the opportunistic control mode as with GUI at the initial stage, while they evenly made transitions among the three modes at the later stage and the practical stage (Fig. 2).

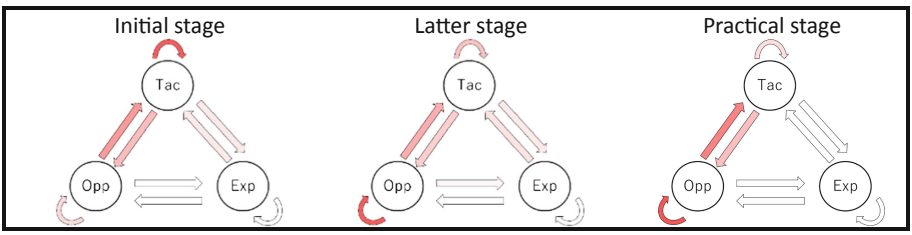

Fig. 1. Transition in GUI

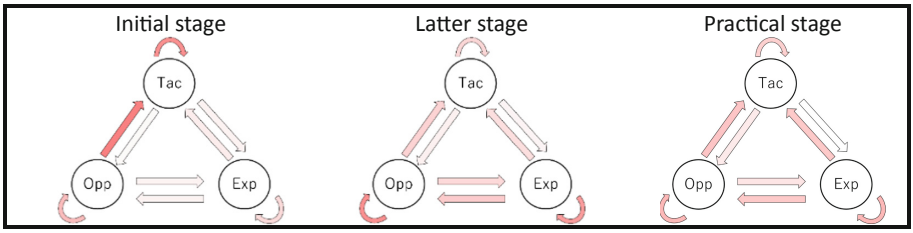

Fig. 2. Transition in TUI

These facts demonstrate that many transitions were made to the tactical control mode at the initial stage. This can be explained by their common idea that they would solve a problem with utilizing their knowledge before getting used to it. In addition, it was revealed that the participants in both interface groups employed the same strategy at the initial stage. At the later stage with GUI, the transition between the tactical control mode and the opportunistic control mode as well as that to the opportunistic control mode were frequently observed. Many transitions to the opportunistic control mode show that they tried to address a problem using their own knowledge without a proper method. In the meantime, their essential strategy had not changed from the initial stage and those in TUI group evenly made transitions among the three modes. This suggests that they not only embraced a strategy to use their own knowledge for addressing problems at a higher difficulty level but also acquired new knowledge by making a transition to the challenging explorative control mode and that they, by interface, employed a different strategy against the problems at a higher difficulty level at the stages where they got used to solving problems. At the practical stage, not a few participants made a transition to the opportunistic control mode. This can be explained by their policy to address the problems requiring an applied skill with the same tactic used at the later stage. As for TUI group, they evenly made a transition among the three mode even at the practical stage. This fact suggests that they tried to take various strategies including the one to use their own knowledge and the one to obtain new strategies for solving a problem requiring an applied skill as they did at the later stage. It was found that they employed different strategies by interface even at the practical stage.

In summary, both GUI group and TUI group addressed the problems using their own knowledge at the initial stage. In addition, while GUI group worked on the problems with utilizing their own knowledge at the later stage as they did at the initial stage, TUI group tried to take a strategy to gain new knowledge, which shows that TUI group used another strategy in addition to the one they employed at the initial stage. At the practical stage, GUI group addressed the problems with taking advantage of their own knowledge as they had done at the initial stage and the later stage. In short, GUI group used the same solving method from the initial stage through to the stage requiring an applied skill. On the other hand, TUI group embraced a strategy to obtain new knowledge even at the practical stage. This demonstrates that TUI group approached problems by employing a new strategy from the later stage and the practical stage on which they became used to solving the problems.

7 Conclusions

A comparative research was conducted for the purpose of verifying the learning process using TUI and GU. Analyses were made from three different perspectives. All of these three analyses revealed in common that the participants in GUI group shared the same approach to solving the problems from the initial stage to the practical stage and that those in TUI group started to employ different solving methods from the later stage when they became familiar with the problems.

It was revealed that the participants in GUI group solved problems while predicting results with the use of their knowledge. For this reason, the participants were unable to solve the problems requiring an applied skill because they approached the problems only with a solving method using their knowledge even if their difficulty level had been raised. Like GUI group, the participants in TUI group addressed the problems while expecting results with the use of their own knowledge. However, at the later stage, in addition to the approach to the problems taking advantage of their knowledge, the participants demonstrated a strategy to design a logic circuit without predicting results for acquiring new knowledge. This fact suggested that the participants in TUI group would develop a different strategy as they got accustomed to solving the problems. Accordingly, it is thought that many participants in TUI group were able to solve all the problems requiring an applied skill since they could get close to correct ones by tentatively designing a logic circuit instead of only using their own knowledge.

8 Application

In normal times, the participants in GUI group approach a problem by utilizing what they have learned as far as possible. In addition, it was revealed that they handled a situation with their acquired knowledge without trying any other method even if encountering an unexpected one that they hadn't learned about. Consequently, they are unlikely to cause errors but may not improve the situation. Meanwhile, in normal times, the participants in TUI group, like GUI group, deal with a situation by taking advantage of what they have learned to the maximum extent possible. However, although they might cause errors when encountering an unexpected situation they have not learned about as they will try various methods in order to remedy it, they are likely to find a method to remedy it eventually. For these reasons, it can be said that while GUI is suitable for routine problems like regular processing, TUI is recommended for the problems frequently requiring irregular processing.

Further, as another utilization method of TUI, it was found that TUI enabled participants to extensively learn how to approach application cases as well as the situations they had previously learned or been trained for. It can be concluded that TUI is suitable for pre-learning and pre-trainings. In actual operations, GUI is appropriate as those using it can handle a situation while taking advantage of the knowledge and experiences obtained through TUI.

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